1uf

NASA TECHNICAL TRANSLATION

NASA TT F-14,770

OPTICAL PROPERTIES OF THE LOWER ATMOSPHERE OF VENUS (INTERPRETATION OF MEASUREMENTS OF THE VENERA 8 SPACECRAFT)

L. G. Titarchuk

(NASA-TT-F-14770) OPTICAL PROPERTIES OF THE LOWER ATMOSPHERE OF VENUS (INTERPRETATION OF MEASUREMENTS OF THE VENERA 8 SPACECRAFT) (Kanner (Leo) Associates) 11 p HC $4.00 CSCL 03B G3/30

N74-20501

Unclas 33676

Translation of "Opticheskiye Svoystva Nizhney Atmosfery Venery (k Interpretatsii Izmereniy AMS Venera 8)," Kosmicheskiye Issledovaniya, Vol. 9, No. 4, 1973, pp. 602-606.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 NOVEMBER 1973

STANDARD TITLE PAGE

1. Report No. NASA TT F-14,770	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle OPTICAL PROPERTIES OF THE LOWER ATMOSPHERE OF VENUS (INTERPRETATION OF MEASUREMENTS OF THE ~~VENERA 8 SPACECRAFT)~~		5. Report Date Nov 73
		6. Performing Organization Code
7. Author(s) L. G. Titarchuk		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates 1013 Van Buren Place Annapolis, Maryland 21405		11. Contract or Grant No. NASw 2481
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address NASA Washington, DC 20546		14. Sponsoring Agency Code
15. Supplementary Notes Translation of "Opticheskiye Svoystva Nizhney Atmosfery Venery (K Interpretatsii Izmereniy AMS Venera 8)," Kosmicheskiye Issledovaniya, Vol. 9, No. 4, 1973, pp. 602-606.		
16. Abstract		
17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified. Unlimited.	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None	9 11	4.00

OPTICAL PROPERTIES OF THE LOWER ATMOSPHERE OF VENUS (INTERPRETATION OF MEASUREMENTS OF THE VENERA 8 SPACECRAFT)

L. G. Titarchuk

The luminance sensor carried by Venera 8 measured the radiation scattered by the atmosphere in the band from 5000 A to 8000 A [1]. The measurements were performed on 23 July 1972. /602

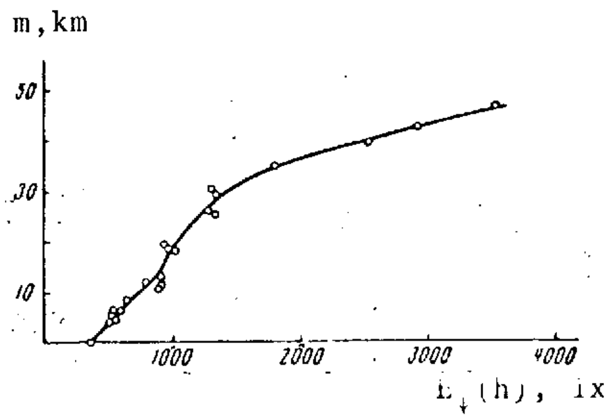
The sensor recorded radiation arriving from the entire upper hemisphere, beginning at an altitude of 50 km and continuing down to the surface of the planet. The zenith distance of the sun during the descent of the apparatus was 85.5 ± 2° [1]. The spectral characteristic of the sensor $f(\lambda)$ is presented in [1]. The descending light flux $E_{\downarrow}(h)$ recorded by the sensor can be represented as follows [1]:

$$E_{\downarrow}=350\int f(\lambda)E_{\downarrow}(\lambda)\,d\lambda, \tag{1}$$

where $E_{\downarrow}(\lambda)$ is expressed in units of $w/m^2 \cdot A$.

The value of $E_{\downarrow}$ is expressed in arbitrary units called luxes [1]. An experimental dependence of the luminance $E_{\downarrow}(h)$ as a function of altitude over the surface of the planet is presented on the accompanying figure.

The curve, adjusted to the experimental points by the least squares method, has two characteristic points at altitudes h = 28 km and 34 km, around which sharp changes occur in the gradient of luminance as a function of altitude. In the first sector $0 \leq h \leq 28$ km, it would be natural to suggest a model of a pure gas medium consisting 100% of CO_2.



Dependence of Descending Light Flux $E_{\downarrow}(h)$ on Altitude h. Circles Represent Experimental Points

Under these assumptions, luminance $E_{\downarrow}(h)$ within this area should change according to the following rule [2]:

$$E_{\downarrow}(h)=\left(1-\frac{{}^{3}/_{4}\tau_{r,0}P(h)/P_0}{1/(1-A_S)+{}^{3}/_{4}\tau_{r,0}}\right)E_{\downarrow}(h_1). \tag{2}$$

Here $\tau_{r,0}$ is the optical thickness of the gas component from 0 to 28 km, $P(h)$ is the CO_2 pressure at /603
altitude h; A_S is the albedo of the surface of the planet, $h = 28$ km, $P_0 = 93$ atm.

In order to prove the likelihood of this model, it is sufficient to use the experimental data to define a certain mean for the spectrum and altitude $\tau_{r,0}$, correct for all altitudes from 0 km to 28 km, and satisfying the interval $4 \leq \tau_{r,0} \leq 27$. This $\tau_{r,0}$ will provide information on the spectral composition of light in this sector. Using (2), we produce an expression for $\tau_{r,0}$:

$$\tau_{r,0}=\frac{4}{3(1-A_S)}\cdot\frac{1-E_{\downarrow}(h)/E_{\downarrow}(h_1)}{P(h)/P_0+E_{\downarrow}(h)/E_{\downarrow}(h_1)-1}. \tag{3}$$

Substituting the ratio of $E_{\downarrow}(h)/E_{\downarrow}(h_1)$ into this formula, taken from the experimental curve and using the data on pressure within the gaseous atmosphere of Venus presented in [3], we produce the following table of the dependence of $\tau_{r,0}$ on altitude (see Table 1).

TABLE 1

h, км	0	4	8	9	11	13	18,5	Mean
$\tau_{r,0}(1-A_s)$	3,67	4,9	7,3	6,8	6,3	4,85	13	7

The mean value of $\tau_{r,0}(1 - A_s)$ is approximately 7, which where $A_s = 0$ corresponds to radiation with $\lambda = 7000$ A. The decrease in $\tau_{r,0}(1 - A_s)$ at low altitudes may be a result of increasing error of the instrument as the descending apparatus enters the high temperature layers. It cannot be excluded that this decrease results from the reflective capacity of the surface $A_s \approx 0.4$. The mean value of $\tau_{r,0} \approx 7$ shows that below 28 km only red light in the 6300 A $\leq \lambda \leq$ 8000 A band penetrates.

Since the gradient $dE_{\downarrow}/dh$ over 28 km differs significantly from the gas value, we can conclude that the primary role in scattering of light in this area is played by an aerosol rather than gas. If we accept 28 km as the lower boundary of the aerosol cloud and 65 km as its upper boundary [3], the indicated geometric thickness of the cloud layer is 37 km. Using a priori estimates of the optical thickness of the clouds [3, 4], as well as the value of the transmission function $V(h, \xi) \leq 0.343$ at the level $h = 46$ km with $87.5° \geq \arccos \xi \geq 83.5°$, we can conclude that at altitudes below 46 km the asymptotic mode of solar radiation scattering obtains [2, 5, 6].

In order to determine the transmission function of the atmosphere, the spectral composition of the light transmitted, attenuation factor α, the single scattering albedo a and the root of the characteristic equation k, let us study the following relationships:

$$\varphi(h) = \frac{1}{E_{\downarrow}} \frac{dE_{\downarrow}}{dh}(65 - h).$$

Substituting the expression for $E_\downarrow(h)$ from [6] and ignoring the derivative of the albedo of the underlying layer with respect to altitude $A'(h)$ [2], as well as the term $6\delta k$ in comparison with $(3 - x_1)(e^{2k\tau_0} - 1)$, we produce the following expression for $\phi(h)$:

$$\varphi(h) = k\tau_0\left\{1 + \frac{2}{e^{2k\tau_0} - 1}\left[1 - \frac{8Ake^{2k\tau_0}}{(e^{2k\tau_0} - 1)[(1 - A)(3 - x_1) + 4k] + 8k}\right]\right\} \tag{4}$$

Here x_1 is the first coefficient in the expansion of the indicatrice $X(\gamma)$ with respect to the Legendre polymonials, τ_0 is the optical depth in the cloud at the level of altitude h, equal to $\alpha(65 - h)$, $\alpha = \text{const}$, $A(h)$ is determined from the corresponding system of equations of [2], $\delta = 1.42$, the values of k, τ_0, A in (4) are functions of altitude and are averaged over the spectrum of the radiation transmitted. The parameter at a given altitude h depends on the form of the indicatrice and the single scattering albedo a. For the case of low true absorption $(1 - a << 1)$, parameter k is defined as follows: $k^2 = (3 - x_1) \cdot (1 - a)$ [6]. We can see from equation (4) that $\Phi(h)$ depends primarily on the produce $k\tau_0$ and weakly on A, k and x_1. Thus, the coefficient with the second term, presented in brackets, where $A = 0.8$-0.9 and $x_1 \approx 2$, decreases monotonically from 1 where $k = 0$ to 0.2 where $k = 0.05$. Table 2 presents values of $\Phi(h)$ taken from the curve of the figure, as well as values of $k\tau_0$, calculated from equation (4) where $x_1 = 2$, $A = 0.8$, $k = 0.05$. Coefficient x_1 is selected on the basis of estimates of the degree of extension of the indicatrice (see [3] and [4]). The value of parameter k is produced as an a priori estimate using the values of spherical albedo A_{sph} according to Irvine [7], $A \approx 0.8$ is the albedo of the lower reflecting layer at the 28 km level. /60

TABLE 2

h, км	$\varphi(h)$	$k\tau_0$	$H_{cl} = 65 - h$, км	h, км	$\varphi(h)$	$k\tau_0$	$H_{cl} = 65 - h$, км
28	1,55	1,54	37	38	1,73	1,73	27
30	1,55	1,54	35	40	1,41	1,39	25
32	1,95	1,95	33	42	1,17	1,11	23
34	2,66	2,66	31	44	0,97	0,91	21
36	2,12	2,12	29				

Analysis of the data presented in Table 2 shows that from 28 km to 34 km the spectral composition of the radiation transmitted changes sharply, i.e., the contribution of short-wave radiation to the transmitted light flux increases with increasing altitude.

Actually, for a fixed wavelength λ, $k\tau_0(h)$ is a monotonically decreasing function of altitude.

In the case where the mean value $\bar{\lambda}$ for $k\tau_0$ depends slightly on altitude h, this smoothness is retained (34 km $\leq$ h $\leq$ 44 km), while on the other hand it is disrupted for a strong dependence of $\bar{\lambda}$ on altitude (28 km $\leq$ h $\leq$ 34 km). The values of $k\tau_0$ at 28 km and 34 km indicate that on the assumption of α = const in the cloud, parameter k_2, averaged over the 6300 A-8000 A subband, is 1/3 the value of parameter k_1, averaged over the 5000 A-6300 A subband, i.e.

$$k(h=34\ \text{км}) = \frac{k_1 + k_2}{2} = \frac{k\tau_0(h=34\ \text{км})}{k_2\tau(h=34\ \text{км})} k_2 \simeq 2k_2, \qquad (5)$$

from which $k_2 = (1/3)k_1$.

In the 10-kilometer sector from 44 km to 34 km, natural attenuation of light due to scattering and true absorption by the aerosol occurs, apparently without significant changes in spectral composition.

Using the dependence of $k\tau_0$ on altitude presented in Table 2, it is not difficult to estimate that parameter k_0, averaged over the 10-kilometer section (34-44 km) is four times greater than the parameter k^0, the mean over the 44-65 km section, i.e., the upper layers of the cloud layer are much more transparent than the lower layers.

In addition to the relative dependence of parameter k on altitude and wavelength λ, these measurements can in principle be used to determine the absolute value of parameter k, but the significant uncertainty of the angle of the sun and the relatively small range of altitudes in the cloud allow us to indicate only /605 the limits of possible change of this parameter. Parameter k can be found best of all from the spherical albedo, if we consider the atmosphere homogeneous and semi-infinite.

According to [6]

$$A_{sph} = 1 - (4k/3 - x_1). \qquad (6)$$

Table 3 presents values of A_{sph} according to Irvine [7] and k calculated where $x_1 = 2$ according to (6). Parameters k_0, k^0, k_1 and k_2 are determined from the values of k from the third column.

TABLE 3

λ, Å	A_{sph}	k	k^0	k_0	k_1	k_2
5012	0,79	0,0525	0,0266	0,107		0,05
6264	0,94	0,015	0,0076	0,0307	0,0163	
7227	0,93	0,0175	0,00882	0,0357		

The corresponding values of single scattering albedo are determined from the relationship $1 - a = k^2$. As follows from the sixth and seventh columns of this table, the ratio $k_1/k_2 = 3$, determined from the reflection of the cloud layer, agrees precisely with the same ratio determined from the transmission of the clouds (5). Knowing k, it is not difficult to estimate the total optical thickness of the clouds and, consequently, the mean volumetric scattering factor. Therefore, we have

$$\tau_0 \approx \frac{k\tau_0(h = 28\ \text{км})}{k_2} \approx 95, \tag{7}$$

$$\alpha = \frac{\tau_0}{H_{cl}} = 2{,}57 \cdot 10^{-5}\ \text{cм}^{-1}. \tag{8}$$

Let us now show the limits of uncertainty of parameter k, caused by uncertainty in the zenith distance of the sun 83.5°-87.5°. Using the expression for the transmission function $V(\tau_0, \xi)$ [6], we can produce an equation for determination of parameter k. Since the equations can be written most easily for the level h = 28 km, let us determine only parameter k_2 at first, then use relationship (5) to determine the full parameter k. Thus, for k_2 we have:

$$0{,}0129 = \frac{\xi u_0(\xi)\, 8k_2 e^{k_2\tau_0}(3 - x_1)}{[(3 - x_1)(1 - A) + 4Ak_2][(3 - x_1)(e^{2k_2\tau_0} - 1) + 6\delta k_2]},$$

$$A = 1 - 1/\left(1 + \frac{3}{4}\tau_{r.0}\right), \quad \tau_{r.0} = 7. \tag{9}$$

Since parameter $k_2 \le 1$, it follows from (9) that $\psi \le 86.5°$. Then, in the range of change of $\psi = 83.5$-$86.5°$, corresponding to the range of $\xi = 0.061$-0.1132, the limits of uncertainty of $k_2 = 0.053$-1. The uncertainty of k_2 with respect to the data for reflection 0.016-0.034 is caused by the error in the measurement of Irvine [7] (±7%). Thus, the most probably values of k_2 lie within limits 0.016-0.053 and the value of $\psi \approx 83.5°$.

We can similarly produce the corresponding intervals for k_1 and τ_0 as 0.05-0.16 and 29-95 respectively.

Thus, the atmosphere of Venus consists of two layers differing sharply from each other in their optical and physical characteristics. In the lower, pure gas layer, located below 28 km, there is conservative Rayleigh scattering. In the upper, cloud layer, extending from 28 km to 65 km, almost conservative adsorption and scattering of visible light occurs ($k \ll 1$), i.e., this layer has great optical thickness. The upper portion of the cloud layer, lying above 44 km, is more /606
transparent than the lower layer. The entire cloud layer is significantly more transparent for radiation in the 6300 A-8000 A band than for radiation in the 500 A-6300 A band.

In conclusion, the author expresses his gratitude to V. I. Moroz and V. G. Kurt for their critical comments in the discussion of this work.

BIBLIOGRAPHY

1. V. S. Avduyevskiy, M. Ya. Marov, B. Ye. Moshkin, A. P. Ekonomov, COSPAR, Constance, 1973.
2. L. G. Titarchuk, Kosmich. Issled., Vol. 11, No. 1, 1973.
3. V. I. Moroz, Uch. Fiz. Nauk, Vol. 104, No. 2, p. 355, 1971.
4. Yu. L. Biryukov, L. G. Titarchuk, Kosmich. Issled., Vol. 10, No. 4, p. 576, 1972.
5. T. A. Germogenova, Zh. Vychislit. Matem. i Matem. Fiziki, No. 1, p. 1001, 1961.
6. V. V. Sobolev, Rasseyaniye Sveta v Atmosferakh Planet. [Scattering of Light in the Atmospheres of the Planets], Nauka Press, Moscow, 1972.
7. W. M. Irvine, J. Atmosph. Sci., Vol. 25, No. 4, p. 610, 1968.